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Assessment of gamma radiation levels in soil samples from Sylhet using High Purity Germanium Detector and Estimation of population exposure

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Abstract

The concentration levels of ^{226}Ra, ^{232}Th and ^{40}K in soil have a great concern in the recent decades, due to its effect on the human health. The radioactivity of some soil samples taken from selected locations in Sylhet District have been measured using a High Purity Germanium Detector based on gamma ray spectroscopy. The present investigation shows that the level of natural radioactivity for ^{226}Ra, ^{232}Th and ^{40}K in such soil is slightly higher than World average value of UNSCEAR,2000. The artificial radionuclide ^{137}Cs was not observed in statistically significant amounts above background level in this study. The radiological hazard parameters i.e., radium equivalent activity, absorbed dose rate, external hazard index, internal hazard index, representative level index and annual effective dose equivalent are calculated from the measured activity concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K from soil samples in this study and compared with the world averages. The experimental soil data were subjected to statistical analysis using IBM SPSS software (version 20). Descriptive statistics of the radionuclides of the soil, Pearson's correlation matrix and Cluster Analysis have been carried out in this study.

Key words: Soil, Gamma ray spectroscopy, Activity Concentration, Radiological hazard parameters, statistical analysis.

Introduction

Concentrations of natural and artificial radionuclides that have been found to depend on the local geological and geographical conditions differ from soil to soil, although these radionuclides are widely distributed [1]. The knowledge of activity concentrations and distributions of the radionuclides in these materials are of greater interest since it provides useful information in the monitoring of environmental radioactivity. The natural terrestrial gamma radiation dose rate is an important contribution to the average dose rate received by the world's population [2,3]. Estimation of the radiation dose distribution is important in assessing the health risk to a population and serve as the reference in documenting changes to environmental radioactivity in soil due to anthropogenic activities [4]. Human beings are exposed

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outdoors to the natural terrestrial radiation that originates predominantly from the upper 30 cm of the soil [5]. Only radionuclides with half-lives comparable with the age of the earth or their corresponding decay products existing in terrestrial material such as ^{232}Th, ^{238}U and ^{40}K are of great interest. Since these radionuclides are not uniformly distributed, the knowledge of their distribution in soil and rock plays an important role in radiation protection and measurement [6]. Gamma radiation from these represents the main external source of irradiation to the human body and the concentrations of these radionuclides in soil are determined by the radioactivity of the rock and also nature of the process of the formation of the soils [7,8] Therefore, radionuclides in soil generate a significant component of the background radiation exposure to the population [9].

The Sylhet region is considered one of the most picturesque and archaeologically rich regions in South Asia. Acid Basin Clays Occupy basin sites in some old floodplain landscapes, mainly in the eastern-Kushiyara floodplain, Sylhet Basin and its piedmont basins [10]. The surface soil, especially the top layer in the earth, is a mixture of various components in the natural environment. Although the main source of U, Th and K is the earth crust, their contents appear at varying levels in the soils of different regions in the world following the variation of the local geology [11]. The study of radionuclides in the soil of Sylhet district is a fundamental step in understanding the behaviour of radioactivity in an ecosystem; these natural radionuclides emit radiation as they disintegrate, and this radiation contributes to the total absorbed dose for people (via ingestion, inhalation and external radiation).

The aim of this work is to measure the specific activity of natural and artificial radionuclides in the soil samples collected from the different area of Sylhet district in Bangladesh using γ-ray spectrometry and to evaluate the radiological hazard of the natural and artificial radioactivity This was accomplished through the following types of measurements: radionuclide activity concentrations in surface soil, outdoor and indoor gamma absorbed dose rate, Radium equivalent activity, the external and internal hazard index and annual effective dose equivalent from soil samples of Sylhet district. The results may be used as a reference data for monitoring possible radioactivity pollutions in future.

Materials and Methods

Physiographic Setting

Sylhet district is located in between 24°36' and 25°11' north latitudes and in between 91°38' and 92°30' east longitudes. The city lies on the banks of the Surma River. Sylhet is situated in north-east Bangladesh which is the divisional capital and one of the four districts in the Sylhet division. Sylhet Division is the north-eastern part of Bangladesh, named after its main city, Sylhet. It is bounded by Meghalaya State of India on the north, Tripura State on the south, Assam State of India on the east and Dhaka division on the west and Chittagong division on the southwest. The city spreads in an area of 3490.40 sq.km and as per Bangladesh Population Census 2001, the population of Sylhet district reached 2.25million. Sylhet has a subtropical climate and lush highland terrain. Silty loam soils were found in Sylhet districts. Sylhet district had calcareous grey floodplain soils. The city produces the highest amount of because the geographical structure of this region is suitable for agriculture [12].

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Figure 1(a): Location of Sylhet District in Bangladesh

Figure 1(b): Map of Sylhet District

Sample Collection and Preparation Techniques

Twenty sampling locations were chosen from all over the city to conduct the radiometric study [Figure 1]. The samples, each 2 kg in weight, were collected in undisturbed, uncultivated, grass covered level areas and in remote locations from man-made structures such as roads and buildings to prevent any external influence on the results. Each soil sample was collected from the area of approximately 2km^2 and up to a depth of 0 to 5 cm. The samples were collected in polythene bags with appropriate code. The collected soil samples were mixed well after removing extraneous materials such as roots, pieces of stones, pebbles etc. Thereafter, soil samples were air dried naturally in the laboratory at room temperature for 10 d and then oven dried at 105°C for about 24 hours [13]. Each soil sample was pulverized, passed through a sieve of 2mm sieve size for homogeneity in powdered form. The dried samples were ground with mortar and pestle and then allowed to pass through a 100-mesh sieve. In order to maintain radioactive equilibrium between ^{226}Ra and its daughters, the homogenized soil samples were then packed in a 500 ml air tight Marinelli beaker, dry-weighed and stored for a period of one month for equilibrium. Each sample was then counted using a gamma spectroscopy device.

Measurement procedures

The gamma spectrometric measurement was carried out using HPGe Gamma ray spectrometric system at the Environmental Radioactivity Monitoring Laboratory, Health Physics Division, Atomic energy centre, Dhaka. The effective volume of the detector was 83.469 cm^3 and energy resolution of the 1.33 MeV energy peak for 60 Co was found as 1.69 keV at full width half maximum (FWHM) with a relative efficiency of 20%. The detector is enclosed in a massive lead shield to reduce background of the system. In addition, the detector was coupled with a computer-based Multichannel Analyzer (MCA) with the MAESTRO (ORTEC) program, which was used for data acquisition and analysis of the gamma spectra. IAEA standard reference materials, Uranium ore (RGU-1) Thorium ore (RG Th-1) and Potassium (RG K-1) of known activity, were used for calibration of the system. The spectrometer was calibrated for energy and efficiency over energy range

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200keV to 2MeV. Each sample was counted for 20,000 seconds to reduce the statistical uncertainty. Minimum measurable activity was determined from the background radiation spectrum and it is 3 Bqkg^{-1} for ^{238}U, 7 Bqkg^{-1}for ^{232}Th and 38 Bqkg^{-1} for ^{40}K with 95% of confidence interval. In the measurements based on the gamma counting system, the activity concentration of ^{40}K was determined using only its gamma energy of 1460.8 keV. The activity concentrations of the ^{238}U and ^{232}Th radionuclides were determined using the energy of their daughter products that occurred during their decay series. The gamma energies were 351.92 & 295.21 keV (^{214}Pb) and 609.31 & 1120.30 keV (^{214}Bi) for ^{238}U, and 911.07 keV and 968.9 keV (^{228}Ac) for ^{232}Th. For artificial radioactivity, the activity concentrations of ^{137}Cs in the soil samples were determined using an energy of 661.7 keV. The activity of each sample was determined using the total net counts under the selected photopeak after subtracting appropriate background counts and applying appropriate factors for photopeak efficiency, gamma intensity of the radionuclide and weight of the sample. The gamma absorbed dose in air at a height of one meter above ground surface is estimated from the activity concentrations of gamma emitting isotopes present in the soil [14].

Theoretical calculations

The activity concentration

The activity concentrations of the radionuclides in the measured samples were computed using the following relation [14],

$$A_s(Bqkg^{-1}) = \frac{C_a}{\varepsilon p_\gamma M_s} \quad (1)$$

where C_a is the net gamma counting rate (counts per second), ε the detector efficiency of the specific γ-ray, P_γ the transition probability of gamma decay and M_s is the mass of the sample (kg).

$$\sigma = \sqrt{\frac{N_S}{T_S{}^2} + \frac{N_b}{T_b{}^2}} \quad (2)$$

where N_s and N_b represent the sample and background counts in time T_s and T_b, respectively. The total uncertainty for each measured sample was calculated taking into account the statistical and other components of uncertainty. The combined uncertainty of the activity was estimated by using the quadratic sum of relevant quantities, which can be defined by Equation (2).

Radium equivalent activity

For the purpose of comparing the radiological effect or activity of materials that contain ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards due to these isotopes, a common index termed as the radium equivalent activity (Ra_{eq}) is used. This activity index provides a useful guideline in regulating the safety standards on radiation protection for the general public residing in the area under investigation. The Ra_{eq} index represents a weighted sum of activities of the above-mentioned natural radionuclides. The index is given as [15]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_k \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the average activity concentration in the sample in Bqkg^{-1} of^{226}Ra, ^{232}Th and ^{40}K respectively.

The absorbed dose rates

The estimation was done in terms of the possible impact of these gamma dose rates emanating from study area where the soil samples were collected. This was estimated for both indoor (D_{in}) nGyh^{-1} and outdoor (D_{out}) nGyh^{-1} gamma dose rate using Equations (3) and (4) respectively.

$$D = [0.427A_{Ra} + 0.662\ A_{Th} + 0.0432\ A_K]nGyh^{-1} \quad (3)$$

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And $D_{in} = 1.4D_{out}$ (4)

where A_{Ra}, A_{Th} and A_K are the same meaning as in equation 2.

External and Internal Hazard indices

The soils are used for manufacturing earthen huts, bricks and pottery materials and, hence, the external radiation hazard index, H_{ex} and internal radiation hazard index, H_{in} were calculated using the following relations [16].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

$$H_{in} = \frac{A_{Ra}}{186} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (6)$$

where A_{Ra}, A_{Th} and A_K are the same meaning as in equation 2.

Annual effective dose rate (AEDR)

The gamma absorbed doses in nGy h^{-1} were converted to annual effective dose (AED) in mSv y^{-1}, as proposed by UNSCEAR (2000). The outdoor annual effective dose rate and indoor annual effective dose rate were calculated using the following equation (7) & (8):

$$AEDR(\mu Svy^{-1}) = D(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.2 \times 0.7(SvGy^{-1}) \times 10^{-3} \quad (7)$$

And

$$AEDR(\mu Svy^{-1}) = D(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.8 \times 0.7(SvGy^{-1}) \times 10^{-3} \quad (8)$$

where D is the absorbed dose rate in air (nGy h^{-1}), 0.7 is the dose conversion factor (Sv Gy^{-1}), 0.2 is the outdoor occupancy factor, 0.8 is the indoor occupancy factor and 8760 is the time conversion factor (h y^{-1}).

Total Annual Effective Dose Equivalent rate is calculated by adding indoor and outdoor AEDER

Total AEDR = AEDR (Indoor) + AEDR (Outdoor) (9)

Representative level index

Radiation risks related with the natural radionuclides of soil samples were estimated through radioactivity level index, Iγr. Representative level index (RLI) is calculated using equation based on the following formula [17]:

$$I_{\gamma r} = \frac{A_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \leq 1 \quad (10)$$

where A_{Ra}, A_{Th} and A_K are the same meaning as in equation 2.

Results and Discussion

Natural radioactivity concentration in soil

The activity concentrations (Bqkg^{-1}) of the naturally occurring ^{226}Ra, ^{232}Th and ^{40}K, radionuclides were determined in the soil samples from Central Sylhet and other part of this district, and the results are given in Table 1. The last four rows of Table 1 contain the average concentrations of the radionuclides measured in soils from different regions of the world, taken from UNSCEAR (2000) and sources in the literature. The specific activity of radionuclides in soil is given in Bqkg^{-1} dry weight. The range of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples under investigation varied from 30.85±3.42 Bqkg^{-1} (S17) to 61.02±9.33 Bqkg^{-1} (S3) with a mean value of 44.44±8.22 Bqkg^{-1}, from 23.43 ± 4. 65Bqkg^{-1} (S5) to 74.71 ± 9.67 Bq.kg^{-1} (S7) with a mean value of 48.02±11.95 Bq.kg^{-1}, from 325.87 ± 9.83 Bq.kg^{-1} (S10) to 529.54±50.90 Bq.kg^{-1} (S13) with a mean value of 420.63± 55.39 Bq.kg^{-1}, respectively.

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Table 1: Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples from Sylhet district

Sample Code	Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples in Bq kg^{-1}		
	^{226}Ra	^{232}Th	^{40}K
S1	39.99 ± 8.02	47.12 ± 11.04	384.89 ± 79.11
S2	45.23±7.70	37.68±12.50	478.22±80.31
S3	61.02±9.33	49.68 ± 6.44	456.88±59.45
S4	43. 50±7.09	51. 50 ±15.21	399 .34± 70.51
S5	52 ± 7.28	23.43 ± 4.65	379.43 ± 56.84
S6	42.52 ± 6.12	50.76 ± 9.19	345.21 ± 40.33
S7	53.07 ± 5.15	74.71 ± 9.67	443.81 ± 62.51
S8	33.55±1.66	42.76±1.19	370.48±36.40
S9	37.91±4.95	46.63±5.61	379.61±49.92
S10	41.08 ± 3.96	33.96 ± 2.92	325.87 ± 9.83
S11	36.29±5.72	34.53 ±4.07	401.25±72.01
S12	35.40 ±2.71	44.8 1 ± 17.5	392.29 ± 31.21
S13	58.28±8.05	64.33 ±10.11	529.54±50.90
S14	39.44±4.01	50.80 ±7.28	521.65±28.35
S15	46.33±5.12	52.23 ±7.10	472.90±54.90
S16	48.83 ± 7.15	38.14 ± 7.34	392.63±44.03
S17	30.85±3.42	40.88±5.17	390.10±53.84
S18	50.18 ± 6.12	64.64 ± 8.10	430.15 ± 41.2
S19	49.10±8.41	58.11 ±6.64	465.13±31.42
S20	41.31±8.30	53.76±8.31	453.19±32.10
Average ± SD	44.44±8.22	48.02±11.96	420.63±55.39
UNSCEAR, 2000	35	30	400
Turkey, 2017	24.5	51.8	344.9
Jordan, 2009	49.9	26.7	291.1
IRAQ, 2015	41.24	21.52	326.74
Nepal, 2021	59.06	69.59	592.46

Figure 2 shows the distribution of ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations in each of the 20 soil samples from the twenty locations of Sylhet district. ^{232}Th activity in the soil samples is distinctly higher than that of ^{226}Ra and the activity of ^{40}K is observed comparatively higher than that of both ^{232}Th and ^{226}Ra in all sampling locations studied. The highest concentration of ^{232}Th was observed in soil sample due to the presence of metamorphic rocks. The abundance of ^{40}K activity was observed in predominantly agricultural areas in the outskirts of the city due to the use of potassium fertilizers and also in the remaining areas because of geological origin. However, a detailed geochemical investigation is required to reach at some conclusion. However artificially produced anthropogenic radionuclide like ^{137}Cs has not been detected in the samples of present research. The

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undetectable anthropogenic radionuclide indicates that no nuclear test activities have been carried out in that region and no fallout of ^{137}Cs radionuclide has occurred. The measured values in the investigated soil samples are found in the order ^{40}K > ^{232}Th > ^{226}Ra > ^{137}Cs. ^{40}K dominates over the other nuclides, which is not unexpected. This is because potassium is the seventh most abundant element in the Earth's crust, making up 2.6% of the weight of the earth's crust [18].

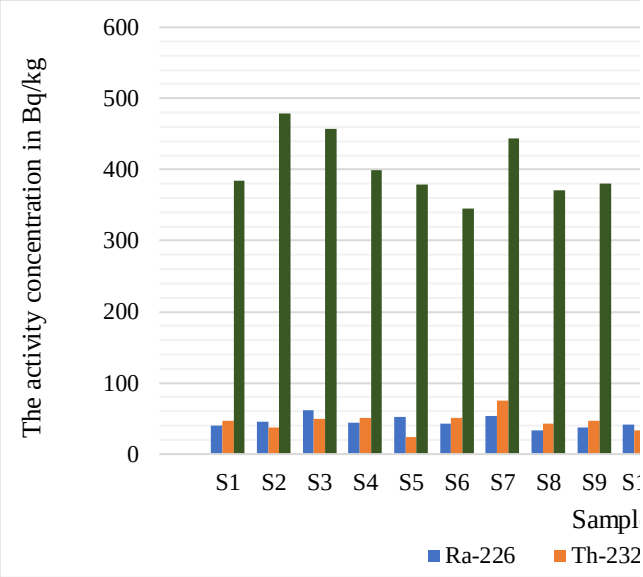
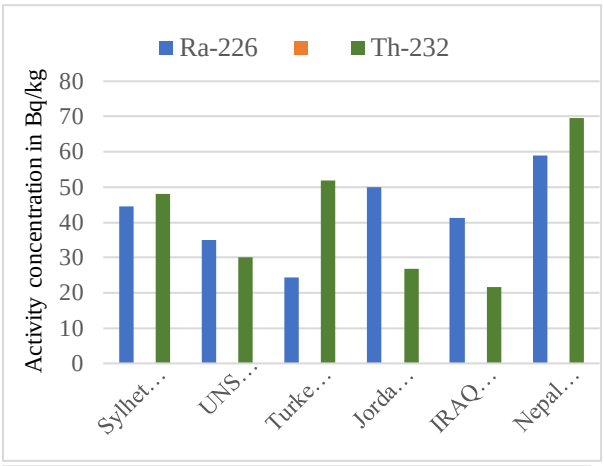
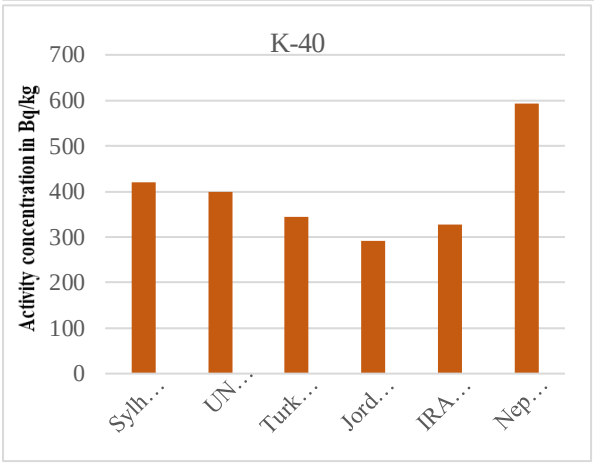


Figure 2: Graphically shows the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from the twenty locations of Sylhet district.

The worldwide levels of naturally occurring radionuclides in soils have an average of 35 $Bqkg^{-1}$ for ^{226}Ra, 30 $Bq.kg^{-1}$for ^{232}Th and 400 $Bq.kg^{-1}$ for ^{40}K according to UNSCEAR 2000. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil sample of Sylhet were found to be higher than the worldwide average concentration of these radionuclides in soils which is shown in figure 3(a) &3(b).





3(a)

3(b)

Figure 3(a) &(b): Comparison of activity concentration of ^{226}Ra, ^{232}Th & ^{40}K in soil samples of Sylhet district, world average and other countries

Radiological hazard parameters

The radiological hazard parameters i.e., radium equivalent activity, absorbed dose rate, external hazard index, internal hazard index, representative level index and annual effective dose equivalent are calculated from the measured activity concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K from soil samples in this study and are shown in Table 2.

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Table 2: calculated values of radium equivalent activity, absorbed dose rate, external hazard index, internal hazard index, representative level index and annual effective dose equivalent

Sample Code	Radium equivalent activity $Bqkg^{-1}$	Outdoor absorbed dose (nGy h^{-1})	Indoor absorbed dose (nGy h^{-1})	External radiation hazard, H_{ext}	Internal radiation hazard, I_{int}	Outdoor annual effective dose equivalent (mSvy^{-1})	Indoor annual effective dose equivalent (mSv y^{-1})	Representative level index, Iγr (Bq kg^{-1})
S1	137.01	64.82	84.26	0.37	0.48	0.079	0.41	0.99
S2	135.93	64.82	84.27	0.38	0.49	0.079	0.41	0.98
S3	167.24	78.59	102.16	0.45	0.62	0.096	0.50	1.20
S4	147.89	69.83	90.78	0.39	0.52	0.085	0.45	1.07
S5	**114.72**	54.03	70.26	0.32	0.45	0.07	0.35	**0.83**
S6	141.68	66.60	86.58	0.38	0.49	0.081	0.42	1.02
S7	**194.07**	91.20	118.56	**0.52**	**0.67**	**0.11**	**0.58**	**1.39**
S8	123.22	58.56	76.13	0.33	0.42	0.071	0.37	0.89
S9	133.82	63.38	82.39	0.36	0.46	0.077	0.40	0.97
S10	114.73	**52.03**	**70.24**	0.32	0.42	**0.066**	**0.34**	0.83
S11	116.56	55.61	72.29	**0.31**	**0.41**	0.068	0.35	0.85
S12	129.68	61.65	80.14	0.35	0.44	0.075	0.39	0.94
S13	191.04	90.24	117.31	0.52	0.66	0.10	0.57	1.38
S14	152.25	72.90	94.77	0.41	0.51	0.089	0.46	1.12
S15	157.43	74.69	97.10	0.42	0.55	0.091	0.47	1.15
S16	133.60	62.98	81.87	0.36	0.49	0.077	0.40	0.96
S17	119.34	57.01	74.11	0.32	0.41	0.069	0.36	0.87
S18	178.72	**83.99**	**109.19**	0.48	0.63	0.103	0.53	1.28
S19	168.01	79.43	103.26	0.45	0.58	0.097	0.51	1.22
S20	153.08	72.71	94.53	0.41	0.52	0.089	0.46	1.11
Mean	**145.50**	**68.85**	**89.51**	**0.39**	**0.51**	**0.084**	**0.44**	**1.06**
±SD	**24.48**	**11.41**	**14.83**	**0.07**	**0.08**	**0.014**	**0.072**	**0.17**

Radium equivalent activity

The radium equivalent factor was estimated using Eq. (2) and the evaluated values are shown in Table 2. The estimated radium equivalent for the samples used ranged from **114.72** to **194.07** $Bqkg^{-1}$ with mean value of **145.50 ± 24.48** $Bqkg^{-1}$. The observed value of Ra_{eq} in all the sample show that soil samples

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labelled with code S5 have the lowest value of Ra_{eq} while the highest is noted in soil sample S7. In comparing the estimated mean of value of 145.50 $Bqkg^{-1}$ with international reference limit of 370 $Bqkg^{-1}$ shown in figure 4(a), it was inferred that mean value determined is within the recommended value as established or reported by15 and 19.

The absorbed dose rates

The contribution of the natural radionuclides to the absorbed dose rate in air (D) depends on the concentration of the radionuclides in the soil. The dose can be calculated using absorbed dose rate conversion factors depending on the radionuclides in the soil. The estimation of outdoor and indoor gamma dose rate was done using Equations 3 and 4. The estimated possible indoor and outdoor gamma dose rates were shown in Table 2. The estimation for the indoor gamma dose rate ranged from **70.24** to **109.19** $nGyh^{-1}$ with mean value of **89.51** $nGyh^{-1}$ while the outdoor gamma dose rate ranged between **52.03** and **83.99** $nGyh^{-1}$ and the mean values was found to be **68.85 ± 11.41** $nGyh^{-1}$. The calculated mean of indoor gamma dose rate (D_{in}) was compared with international reference value of 80 $nGyh^{-1}$ [15], the observation showed that the indoor gamma dose rate of the soil samples used is higher than recommend limit [15]. Furthermore, estimated mean of outdoor gamma dose rate (D_{out}) was compared with international reference value of 50 $nGyh^{-1}$ as reported by 20, it was noticed that the estimated value the soil samples is higher in figure 4(b), which may be as a result of geological formations which predominantly underlying the study area.

Estimation of External and internal hazard

The estimation of external risk assessment (H_{ex}) associated to gamma dose rays emanating from the soil sample were determined using Eq. (5) 25,23. The values estimated for external risk in the soil samples are shown in Table 2. The evaluated external risk ranged between **0.31** and **0.52**. The mean value of external risk was estimated to be **0.39±0.07**. The valuation of internal risk assessment (H_{in}) associated to gamma dose rays emanating from the soil sample were determined using Eq. (6) 25,23. The values assessed for internal risk in the soil samples are shown in Table 2. The evaluated internal risk ranged between **0.41** and **0.67**. The mean value of external risk was estimated to be **0.51±0.08**. The highest value of Hex and H_{in} both are noted in soil sample S7 and the lowest value for both risk assessments observed in soil sample S11. The acceptable limit for hazard in soil is unity or 1, in this present study, the estimated value of Hex and H_{in} risk values for each sample were within the standard value of unity as recommended by 6. However, the mean values of H_{ex} and H_{in} values for the measured areas do not exceed the limit (<1) recommended by UNSCEAR-2000. The calculated values of the external hazard index and internal hazard index are lower than the safe limits which is graphically shown in figure 4(c). The results show that the H_{ex} and H_{in} values for the soil samples are below the limit of unity, meaning that the radiation dose is below the permissible limit of 1 $mSvy^{-1}$ as recommended by IAEA.

Annual effective dose rate equivalent (AEDR)

The Indoor and outdoor annual effective dose rates equivalent for the sample used in this study was evaluated using Eq. (7) & (8). Indoor and outdoor AEDE values are presented in table 2. Values of indoor and outdoor AEDE are found to be in the range from **0.34** to **0.58** $mSvy^{-1}$ and **0.066** to **0.11** $mSvy^{-1}$ respectively. For indoor, values of AEDE are found to be

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higher than outdoor because people spend more time inside the houses as compared to outside. Average value of indoor AEDE was found to be 0.44±0.072 mSvy^{-1} and average outdoor annual dose rate was found to be 0.084 ±0.014 mSvy^{-1}. Total average AEDE was found to be 0.524 mSvy^{-1} using equation (9). As per UNSCEAR report, the annual effective dose due to total cosmic and cosmogonic radiation is 0.39 mSv and for total external terrestrial radiation is 0.48 mSv based on average worldwide values with a total of AEDE 0.87 mSvy^{-1} [21] . Present study indicates the values of AEDE from Sylhet district of Bangladesh to be lower than the above-mentioned world average that is shown in figure 4(d). The data reported in this study will seem as useful baseline data for this region.

Representative level index

The representative level index is used to estimate the level of gamma radiation hazard associated with the natural radionuclides in soil sample. It is a screening tool for identifying materials that may be hazardous to health. It is correlated with the annual dose due to the excess external gamma radiation caused by superficial material. The safety value for this index is ≤ 1. The representative level index for soil samples are displayed in Table 2 and Figure 4(e). The calculated *RLI* varies from **0.83** to 1.39 with an average of **1.06 ±0.17.** It is clear that this average value exceeds the upper limit of the *RLI*, which is unity.

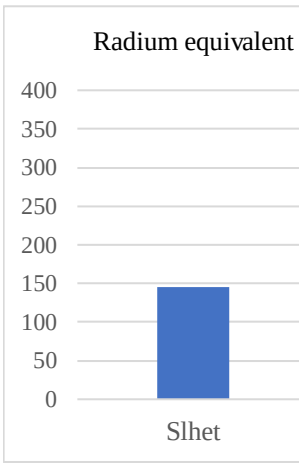

Figure 4(a): Radium equivalent activity (Bqkg^{-1})

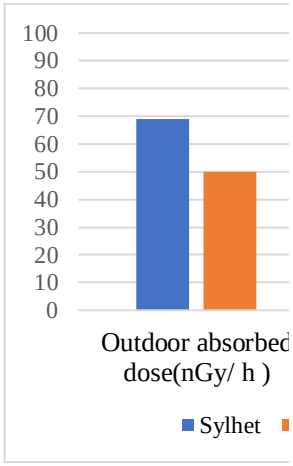

Figure 4(b): Absorbed dose rate (nGyh^{-1})

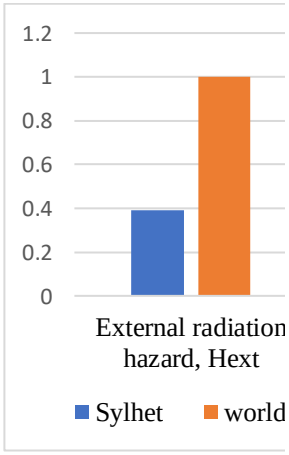

Figure 4(c): External and Internal Radiation hazard Index

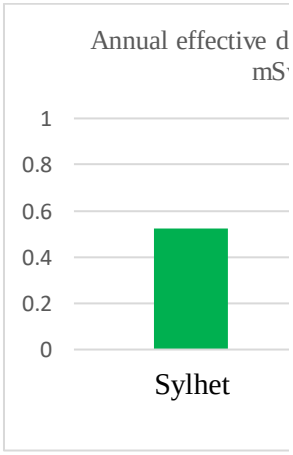

Figure 4(d): Annual effective dose rate equivalent (mSvy^{-1})

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IJLST (2022), 14(2):13-28

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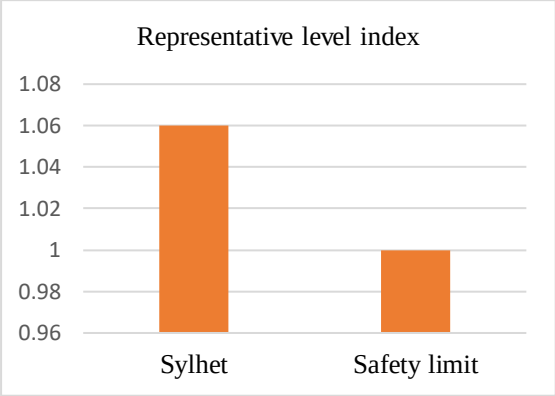

Figure 4(e): Representative level index

Figure 4(a),4(b),4(c),4(d) &4(e): Radiological hazard parameters i.e., radium equivalent activity, absorbed dose rate, external hazard index, internal hazard index, representative level index and annual effective dose equivalent.

Descriptive statistics

The experimental soil data were subjected to statistical analysis using IBM SPSS software (version 20). Descriptive statistics of the radionuclides of the soil are given following table 3. The largest standard deviation was obtained for ^{40}K and smallest for ^{226}Ra. In statistical analyses skewness is a measure of symmetry whereas kurtosis is a measure of whether the data are heavy-tailed or light-tailed relative to a normal distribution [22]. The activity concentrations of ^{226}Ra and ^{40}K in this study have negative kurtosis values, which indicate that the distributions are flat in nature whereas ^{232}Th has positive kurtosis showing a peaked distribution. In the present study, the distributions associated with ^{226}Ra, ^{232}Th and ^{40}K radionuclides have positive skewness values, indicating asymmetric distribution with extended tail that are more positive, from histograms it's clear that ^{226}Ra and ^{232}Th were distributed in normal distribution whereas ^{40}K shows few degrees of multi-modality. This multimodality indicates that complexity of minerals in soil samples.

Table 3: Descriptive statistics of ^{226}Ra, ^{232}Th and ^{238}U in different soil samples

Variables	^{226}Ra	^{232}Th	^{40}K
Range	30.17	51.28	203.87
Minimum	30.85	23.43	325.87
Maximum	61.02	74.71	529.54
Mean	44.44	48.02	420.62
Std. deviation	8.22	11.95	55.38
Skewness	0.366	0.225	0.399
Kurtosis	-0.534	0.446	-0.472

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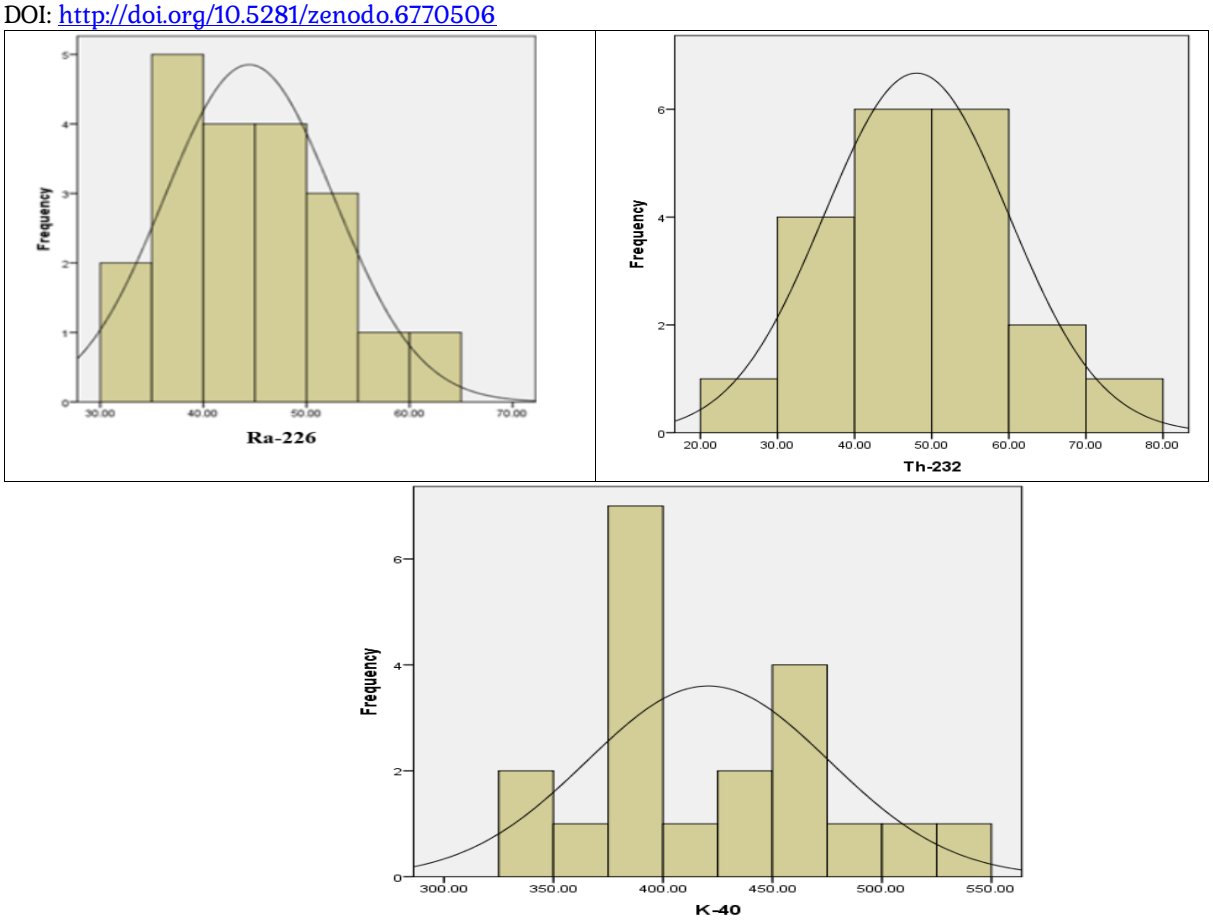

Figure 5: Frequency distribution of ^{226}Ra, ^{232}Th & ^{40}K.

Pearson's Correlation Matrix Analysis

The Pearson's correlation matrix reveals that the association between the natural occurring radionuclides and the radiological hazards parameters calculated for different soil samples. All radiological parameters show strong positive correlation with ^{232}Th and significant positive correlation with ^{226}Ra and ^{40}K respectively. It reveals that the gamma radiation in collected soil samples originated from all of the measured radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil sample. The higher correlation values between radiological hazards parameters and ^{232}Th signify that ^{232}Th has more powerful effects in radiation hazards than ^{226}Ra, and ^{40}K respectively. Gamma radiation representative level index (Iγr) also strongly correlated with ^{232}Th than ^{226}Ra, and ^{40}K and it also indicate that the gamma emission in soil sample mostly originated from ^{232}Th.

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Table 4. Pearson correlation matrix analysis for all radiological parameters & radionuclides found in soil sample

Correlations											
Parameters	^{226}Ra	^{232}Th	^{40}K	Dose (Out)	Dose (in)	AEDE (Out)	AEDE (in)	H_{ex}	H_{in}	Ra_{eq}	Iγr
^{226}Ra	1										
^{232}Th	.407	1									
^{40}K	.461*	.510*	1								
Dose (Out)	.686**	.925**	.704**	1							
Dose (in)	.686**	.925**	.704**	1.000**	1						
AEDE (Out)	.686**	.925**	.704**	1.000**	1.000**	1					
AEDE (in)	.686**	.925**	.704**	1.000**	1.000**	1.000**	1				
H_{ex}	.700**	.924**	.685**	.999**	.999**	.999**	.999**	1			
H_{in}	.824**	.843**	.668**	.977**	.977**	.977**	.977**	.982**	1		
Ra_{eq}	.700**	.924**	.685**	.999**	.999**	.999**	.999**	1.000**	.982**	1	
Iγr	.691**	.922**	.707**	1.000**	1.000**	1.000**	1.000**	.999**	.979**	.999**	1
*. Correlation is significant at the 0.05 level (2-tailed).											
**. Correlation is significant at the 0.01 level (2-tailed).											

Cluster analysis

Hierarchical Cluster Analysis (HCA) is a multivariate statistical analysis which is used to classify the objects of the system into groups based on their similarities and to find an optimal grouping for which the observations or objects within each group are similar, but the groups are dissimilar from each other [22]. In this study, HCA with average linkage method is further employed to explore the associations between radionuclides and radiological parameters. Three clusters are distinguished in figure. 6.

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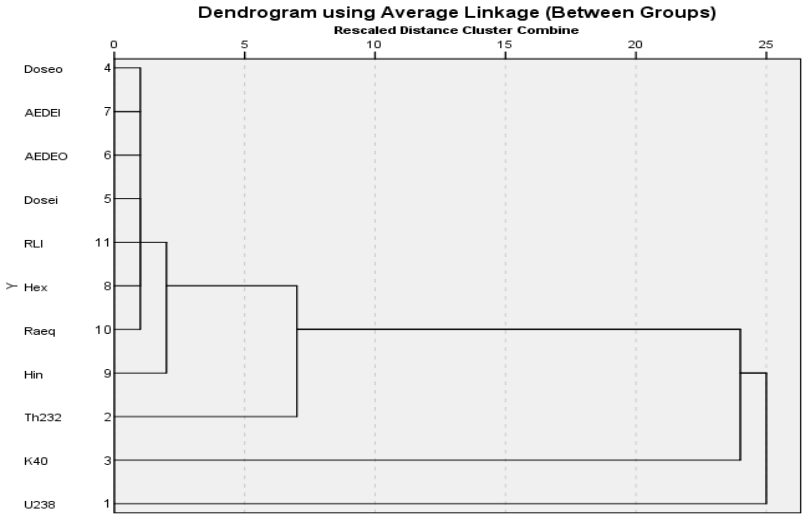

Figure 6: Dendrogram shows the clustering radiological parameters.

The first cluster is composed of ^{232}Th, Dose (both outdoor and indoor), RLI (Iγr), AEDE (both outdoor and indoor), Ra_{eq} , H_{ex} and H_{in}. In this cluster radiological hazards parameters are more related to activity concentration of ^{232}Th. H_{in} and ^{232}Th are sub-grouped in first cluster and close to Ra_{eq}. The second cluster consisted of ^{40}K solely. Presumably ^{40}K is originated in soil as primordial single occurrence radioisotope. The third cluster also consisted of ^{226}Ra solely. After ^{232}Th, ^{40}K is closer to radiological hazards parameters than ^{226}Ra. The result revealed from cluster analysis is consisted with Pearson's correlation matrix analysis.

Conclusions:

The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil sample of Sylhet were found to be higher than the worldwide average concentration of these radionuclides in soils. The artificial radionuclide ^{137}Cs was not detected in the samples of the present study. It seems that there is no fresh nuclear fallout in places under study. The value of Radium Equivalent Activity Ra_{eq} is found to be about 2.5 times less than the permissible maximum value of 370 $Bq.kg^{-1}$. The calculated mean of indoor gamma dose rate (D_{in}) and outdoor gamma dose rate (D_{out}) were compared with international reference value of 80 $nGyh^{-1}$ and 50 $nGyh^{-1}$ respectively, the observation showed that the indoor gamma dose rate (D_{in}) and outdoor gamma dose rate (D_{out})of the soil samples used is higher than recommend limit. The H_{ex} and H_{in} values for the soil samples are below the safe limit (<1) recommended by UNSCEAR-2000. The value of AEDE from Sylhet district of Bangladesh to be lower than the above-mentioned world average. The data reported in this study will seem as useful baseline data for this region. The Pearson correlation analysis and cluster analysis were employed to analyses the data and it reveals that the activity concentration of ^{232}Th possesses prominent effect on radiological hazards parameter rather than ^{226}Ra and ^{40}K.

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